USE OF HIS BUNDLE RECORDINGS IN UNDERSTANDING A-V CONDUCTION DISTURBANCES*

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THE ability to record electrical activity of the specialized conduction tissues, including the A-V node, bundle of His, and the right and left bundle branches by means of an electrode catheter technique has enhanced our knowledge of various aspects of A-V conduction in man.[1-27] The recording of A-V nodal (N), bundle of His (H), and right bundle-branch (RB) potentials using an electrode catheter which is percutaneously introduced into a femoral vein and fluoroscopically positioned in the region of the tricuspid valve is relatively simple and safe. Figure 1 illustrates these recordings, which were obtained in a patient with LBBB. The A-H interval which is measured from the onset of the atrial electrogram to the onset of the His deflection is taken as a measure of A-V nodal conduction time. The H-V interval is measured from the onset of the His deflection to the onset of ventricular depolarization and reflects His-Purkinje conduction time. The normal H-V intervals range from 30 to 55 msec. with an average of 45 msec.

Recordings of N, H, and left bundle-branch (LB) potentials can also be obtained by positioning the electrode catheter in the region of the posterior or noncoronary aortic cusp (Figure 2). Right and left bundle-branch potentials can also be recorded by introducing the catheter into the ventricular cavities.

Validation of His potentials is presented in Figure 3. Panel A depicts H potentials recorded simultaneously by three different methods. The

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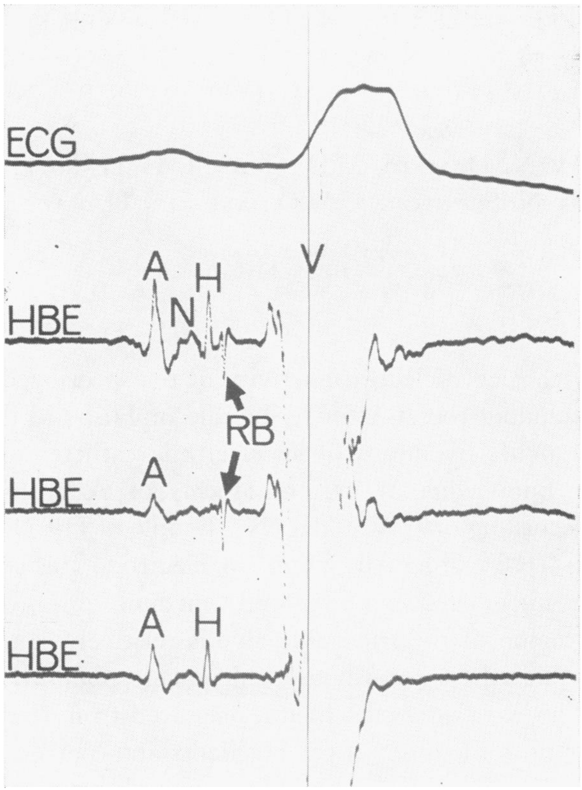

Fig. 1. Simultaneous recordings of A-V nodal (N), His bundle (H) and right bundle-branch (RB) potentials recorded in a patient with LBBB using a tripolar electrode catheter. A=atrial electrogram, V=ventricular electrogram. ECG=Lead II of standard electrocardiogram. Reproduced by permission from: Damato, A. N. and Lau, S. H. *Progr. Cardiov. Dis. 13*:123, 1970.

HBE (left) was recorded from an electrode catheter positioned in the posterior aortic cusp. The HBE (right) records His bundle activity from an electrode catheter positioned in the region of the tricuspid valve. The HBE (wire) records electrical activity from close bipolar wires inserted directly into the region of the common bundle. In Panel B, electrical stimulation of the His bundle using the plunge wires results in normal QRS complexes. The interval from the stimulus artifact to the onset of ventricular depolarization (S-V interval) is the same (35 msec.) as the H-V interval during sinus rhythm.

First Degree Heart Block

In our experience the most common cause of first degree heart block (P-R interval > 0.20 sec.) results from conduction delay within the A-V node. This is reflected in a prolonged A-H interval as illustrated in Figure 4. Figure 5 demonstrates an example in which first degree heart block was due to conduction delay in both the A-V node (A-H interval) and His-Purkinje system (H-V interval). When digitalis produces first degree heart block, it does so by increasing the A-H interval. Similarly the progressive prolongation of the P-R interval which results whenever the atria are electrically stimulated at increasing rates above the sinus rate is the result of A-V nodal delay.

Type I Second Degree Heart Block

Type I second degree heart block is electrocardiographically characterized by a progressive prolongation in the P-R interval followed by a nonconducted atrial impulse. This electrocardiographic pattern is most commonly due to conduction delay and block in the A-V node. A typical example of Type I A-V block is illustrated in Figure 6.

Classically, the P-R interval shows progressive lengthening with decreasing increments of delay, associated with shortening of the ventricular cycle length. The greatest increment of delay occurs in the second conducted beat. The experimental studies of Watanabe and Dreifus have shown that any combination of length of cycles may occur, depending upon the relative degree of delay in various portions of the A-V conducting system.[24] In our experience during A-V nodal Wenckebach induced by atrial pacing, the greatest increment of delay commonly occurs in the last conducted beat.

Atypical Wenckebach

Figure 7 is an unusual variant of Type I second degree A-V block. The atrial impulses are conducted with increasing increments of A-V nodal delay with a constant H-V interval. The fourth atrial impulse is blocked below the bundle of His with an unexpectedly short A-H interval of 135 msec. This phenomenon might be called "concealed supernormal A-V nodal conduction" since the fourth atrial impulse is conducted with a normal A-H interval at a time when one would expect greater delay or even block within the A-V node. A more likely

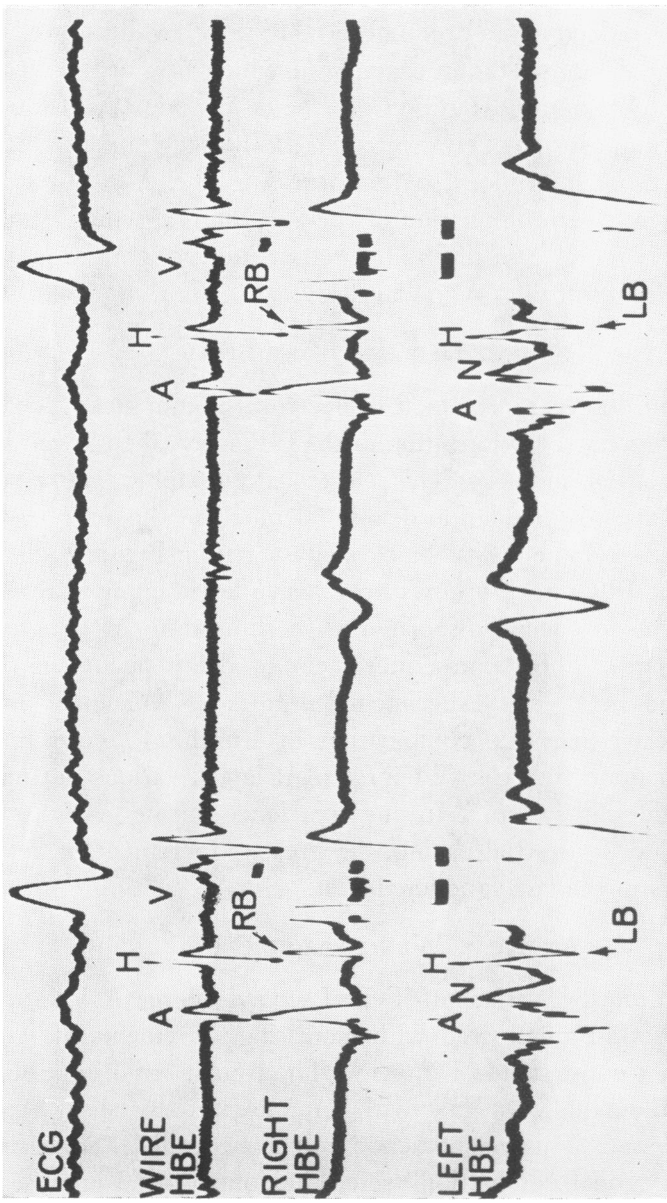

Fig. 2. Simultaneous records of A-V nodal (N), His bundle (H), right bundle-branch (RB), and left bundle-branch (LB) potentials in a canine heart. The top HBE tracing was recorded using close bipolar wires inserted into the region of the common bundle. The middle HBE tracing was recorded by using a tripolar electrode catheter positioned in the region of the tricuspid valve. The bottom HBE tracing was obtained from an electrode catheter positioned in the posterior or noncoronary aortic cusp. The H deflections are recorded simultaneously and are followed by the RB and LB potentials.

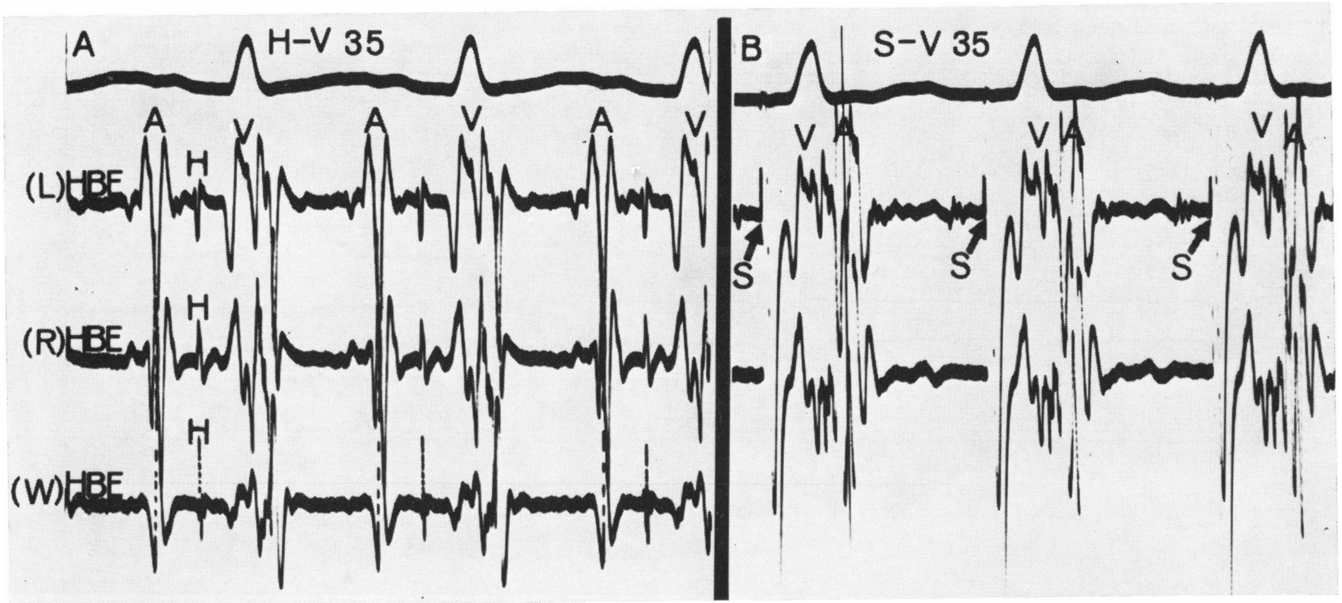

Fig. 3. *Panel A:* Simultaneous recordings of His bundle activity. Left HBE = electrode catheter positioned in the posterior or noncoronary cusp. Right HBE = electrode catheter positioned at tricuspid region. Wire HBE = close bipolar wire inserted into region of common bundle. The H-V interval during sinus rhythm measures 35 msec. *Panel B:* Electrical stimulation of the common bundle using the plunge wires results in S-V interval of 35 msec. and a normal QRS complex. The same results were obtained when the common bundle was stimulated through either of the electrode catheters.

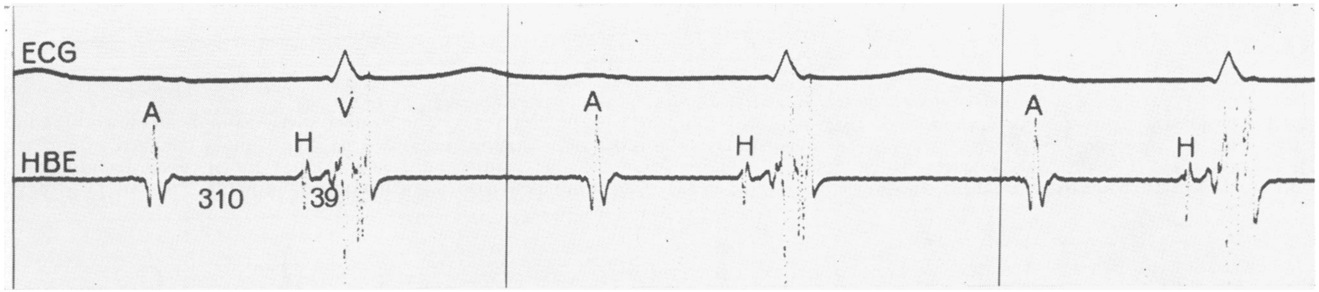

Fig. 4. First degree heart block due to A-V nodal delay. The H-V interval of 39 msec is within normal limits. Reproduced by permission from: Lau, S. H. and Damato, A. N.: *Cardiov. Clin. 2*:50, 1970.

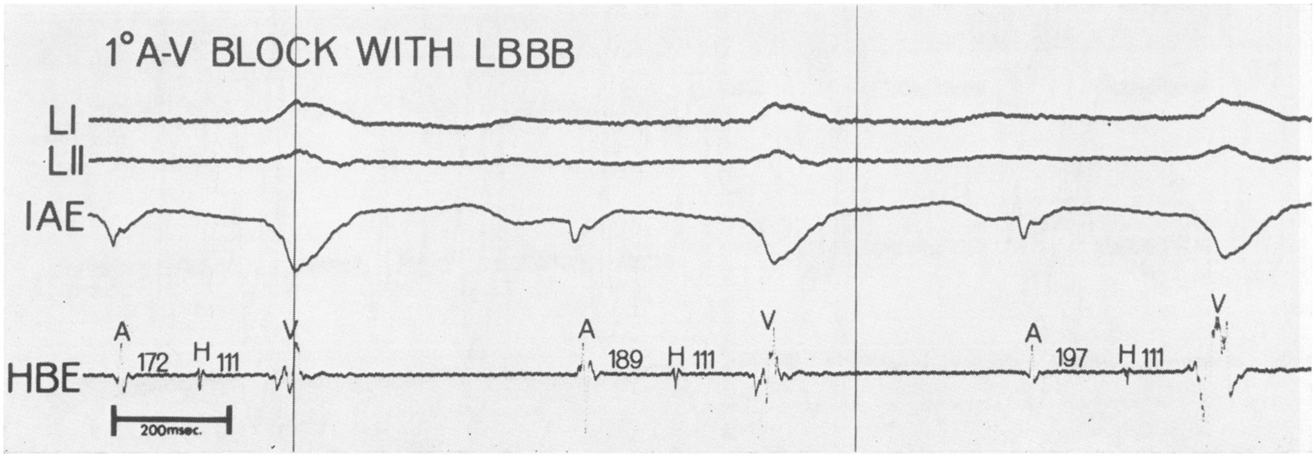

Fig. 5. First-degree heart block due to conduction delay within both the A-V nodal and His-Purkinje systems. L 1 and L 2 are leads 1 and 2 of the standard electrocardiogram. IAE = intra-atrial electrogram. Reproduced by permission from: Damato, A. N. and Lau, S. H.: *Progr. Cardiov. Dis. 13*:123, 1970.

explanation is that during the long A-V nodal delay of the preceding cycle (A-H 360 msec.) the upper and middle portions of the A-V node recovered. In the presence of a fully recovered A-V nodal system, the fourth atrial impulse blocks below the bundle of His because the ventricular cycle length changes (long-short sequence) and does not represent pathology of the His-Purkinje system. The localization of block within the His-Purkinje system in this unusual variant of Type I A-V block is not an indication for pacemaker therapy (see below).

A-V Nodal Wenckebach Produced by Concealed Bundle of His Extrasystoles

In 1947 Langendorf and Mehlman proposed that concealed bundle of His extrasystoles could produce Type I and II second degree A-V block.[25] Recently this unusual form of cardiac arrthythmia has been clinically and experimentally validated using bundle of His recordings.[22, 26] Figure 8 is an example of Type 1 block produced by coupled premature bundle of His extrasystoles in the dog. Following each sinus beat, the bundle of His was prematurely stimulated at an H-S coupling interval of 210 msec. The bundle of His extrasystoles failed to propagate antegradely (no ventricular response) because the ventricular specialized conducting system was refractory. The His extrasystoles were retrogradely propagated into the A-V node and concealed as reflected in the progressive prolongation and block of the subsequent sinus impulses. This unusual form of Type I A-V block should be suspected when QRS complexes of junctional origin are seen in other portions of the electrocardiogram. Concealed His extrasystoles may produce Type I and II A-V block in the same patient.

Wenckebach Within the Bundle of His

Uncommonly, the electrocardiographic manifestations of Type I A-V block can be produced by conduction delay and block within the bundle of His itself. Figure 9 represents such a phenomenon, which was recorded in experiments on dogs in which the common bundle was injured. The P-P intervals are constant and the QRS complexes are of normal duration and configuration. The HBE tracing reveals two sharp His deflections, H and H′ during sinus rhythm. The A-H interval of 55 msec. and the H-V interval of 30 msec. were constant for all beats. The H-H′ interval increased from 25 to 55 msec., with block occurring

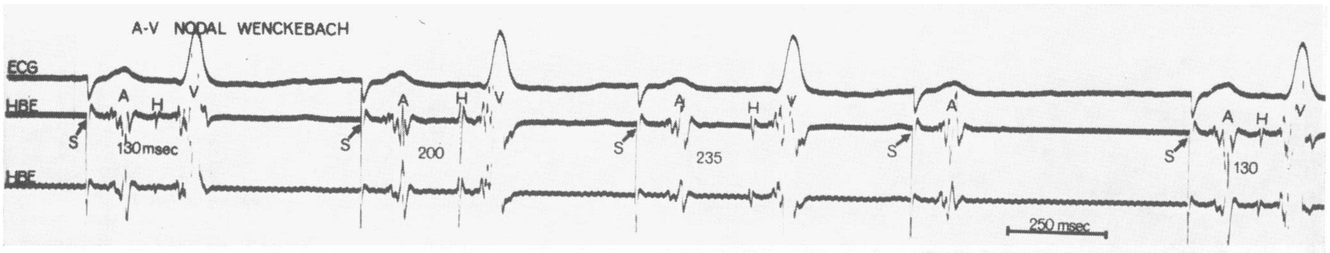

Fig. 6. Type 1 second-degree heart block. There is a progressive increase in A-V nodal conduction time as reflected in the increasing A-H intervals. The H-V intervals remain constant. The fourth and nonconducted atrial impulse is blocked proximal to the bundle of His. Reproduced by permission from: Lau, S. H. and Damato, A. N. *Cardiov. Clin. 2*:50, 1970.

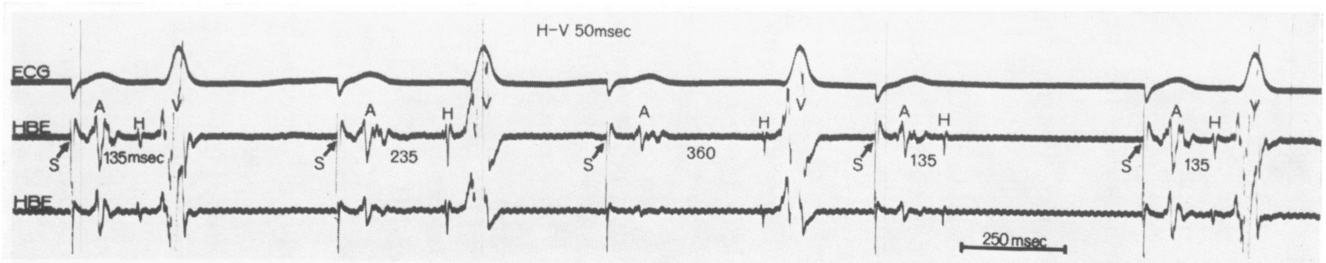

Fig. 7. Atypical Type 1 second degree A. V. block in which the nonconducted atrial impulse is blocked distal to the bundle of His with an unexpectedly short (normal) A-H interval. Reproduced by permission from: Gallagher, J. et al. *Couer Med. Interne.* In press.

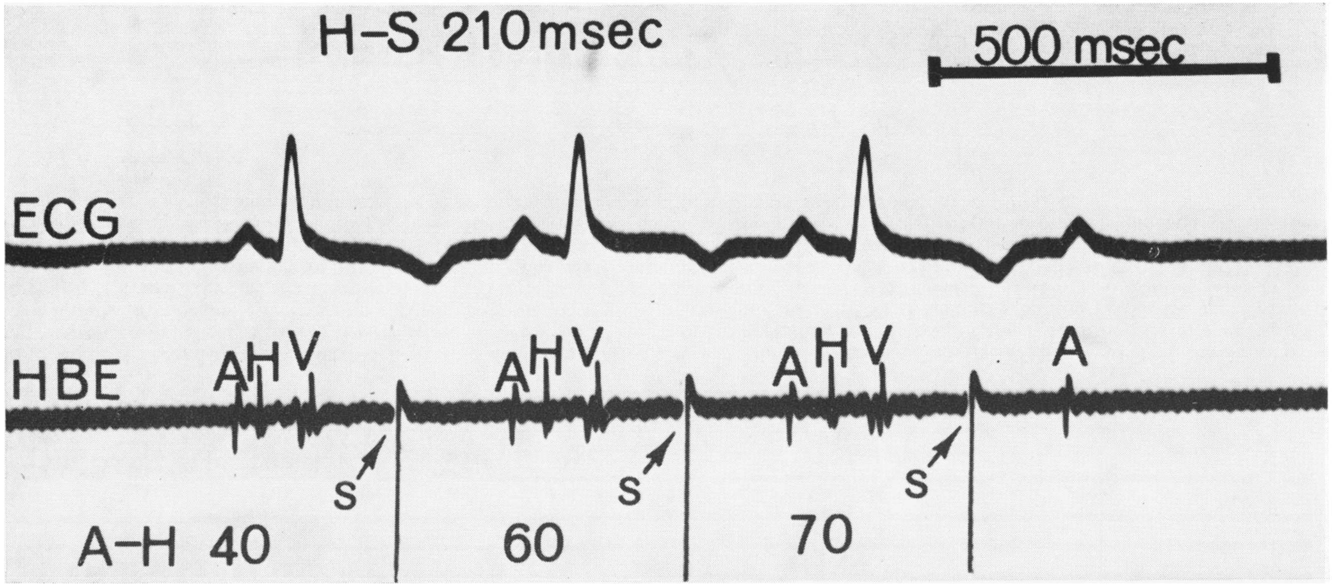

Fig. 8. Type 1 second-degree heart block resulting from concealed bundle of His extrasystoles. Following each sinus beat the bundle of His is prematurely stimulated at an H-S coupling interval of 210 msec. The premature His stimulus does not conduct antegradely (no ventricular response) but is concealed retrogradely in the A-V node causing the subsequent A-H intervals to increase and finally blocking the fourth atrial impulse. Reproduced by permission from: Gallagher, J. et al. *Couer Med. Interne.* In press.

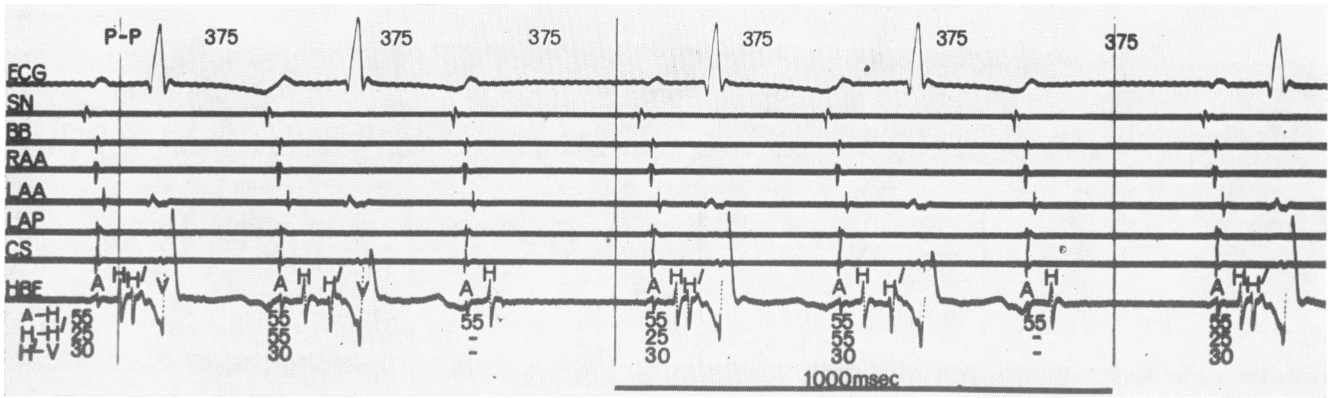

Fig. 9. Type 1 second-degree heart block produced by conduction delay within the common bundle. ECG = lead 2 of the standard electrocardiogram. The P-P interval is constant at 375 msec. There is a progressive prolongation of the P-R interval and every third atrial impulse is blocked. Electrogram recordings from the regions of the sinus node (SN), Bachman's bundle (BB), the right atrial appendage (RAA), the left atrial appendage (LAA), the posterior position of the left atrium (LAP), and the coronary sinus (CS) denote the antegrade sequence of atrial activation. The HBE tracing reveals that there are two His deflections, H and H1. A-V nodal conduction as reflected in the A-H interval is constant at 55 msec. Conduction within the common bundle as reflected in the H-H1 interval increases from 25 to 55 msec. for the first two beats of the cycle. The third atrial impulse is blocked within the common bundle. The H-V interval of the conducted beats recains constant at 30 msec.

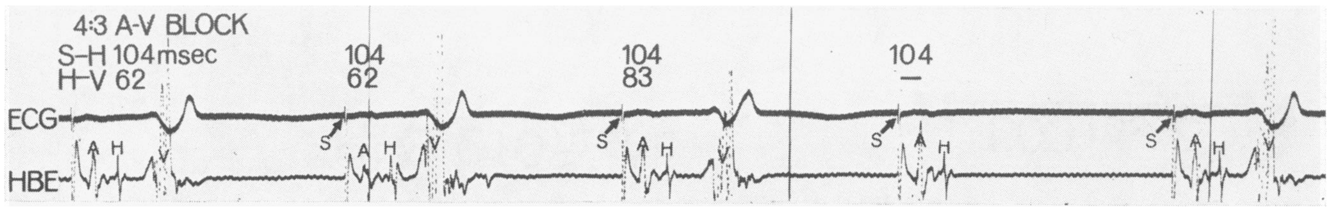

Fig. 10. Wenckebach within the His-Purkinje system. Patient with RBBB and LAD. During constant atrial pacing the P-R interval increased and was followed by a blocked atrial impulse. The S-H intervals are constant. The H-V interval of the third beat increases to 83 msec. and the fourth atrial impulse is blocked below the bundle of His.

below the H deflection every third beat. This represented a 3:2 Wenckebach type of conduction within the common bundle. That the two deflections do not represent His and bundle-branch potentials is supported by the fact that the morphology of the QRS complexes remained constant. A conduction delay of 30 msec. between the His and a bundle-branch potential would be expected to produce a change in the QRS complex.

Wenckebach Within the His-Purkinje System in Man

Figure 10 is an example of the Wenckebach phenomenon occurring within the His-Purkinje system of a patient with RBBB. During atrial pacing the A-H intervals remained constant. The H-V interval of the first two atrial beats is constant. An increase in the H-V interval occurs with the third atrial beat and the fourth atrial impulse blocks below the bundle of His. Since this patient had a preexisting right bundle-branch block pattern, the QRS complexes essentially did not change during the conduction delay within the His-Purkinje system. While this form of A-V block simulates the electrocardiographic pattern of Type I, the pathophysiology and therapeutic implications are more in keeping with Type II A-V block.

Supraventricular Tachycardia (STV) Initiated by A-V Nodal Wenckebach Cycles

On occasion the A-V nodal delay seen during Wenckebach cycles was the setting for sustained reentrant supraventricular tachycardia in addition to atrial echoes. This is illustrated in Figure 9. The patient was a 44-year-old woman with varying degrees of RBBB and LAH, presenting with a history of episodic tachycardias of sudden onset and offset. The first complex is a normal sinus beat with an A-H interval of 110 msec. and an H-V interval of 50 msec. The sequence of atrial activation is from high to low atrium. Atrial pacing was begun at 120/min. The A-H interval of the first three paced beats increased from 120 to 160 msec. During the A-V nodal delay of the third paced beat, reentry occurred within the A-V node and SVT was initiated at a rate of 154/min. The fourth and fifth stimuli were ineffective. The sequence of atrial depolarization during SVT is reversed, proceeding from low artrial septum to high atrium, and is associated with inverted P waves in leads II and III. The diagramatic bars are merely a visual aid

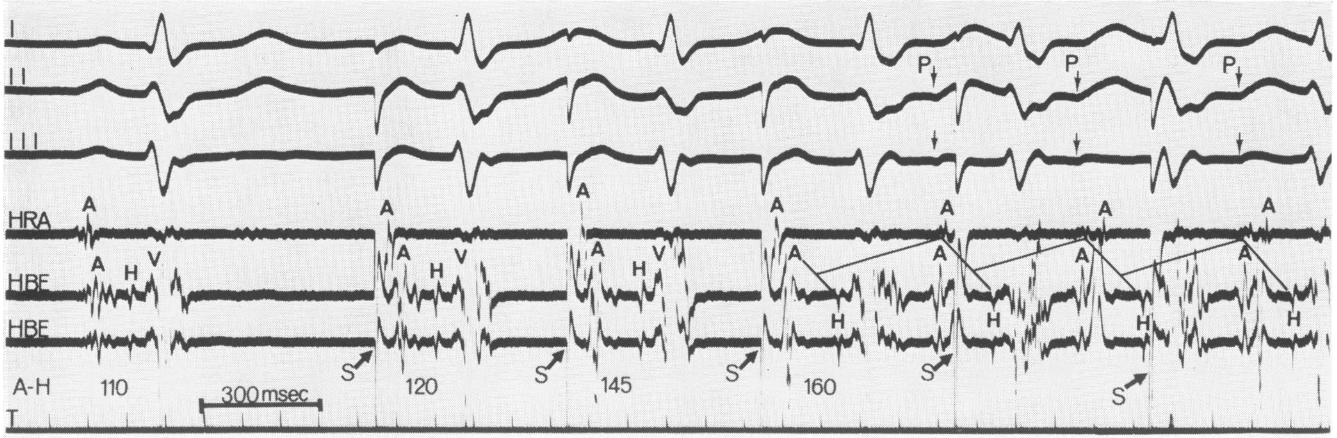

Fig. 11. Supraventricular tachycardia initiated during Type 1 second-degree A-V block. 1, 2, and 3 refer to standard electrocardiographic leads. HRA = high right atrial electrogram. HBE are simultaneous His bundle electrogram recordings. T = time lines. S = denotes the stimulus artifact delivered to the right atrium during pacing. The first beat is a sinus beat. Note the high-low sequence of atrial depolarization. With the onset of atrial pacing there occurs a progressive increase in A-V nodal conduction time. At an A-H interval of 160 msec. the atrial impulse reenters within the A-V node and initiates a supraventricular tachycardia. Note that the sequence of atrial activation becomes low-high and that the P waves are inverted. Reproduced by permission from: Gallagher et al. *Couer Med. Interne.* In press.

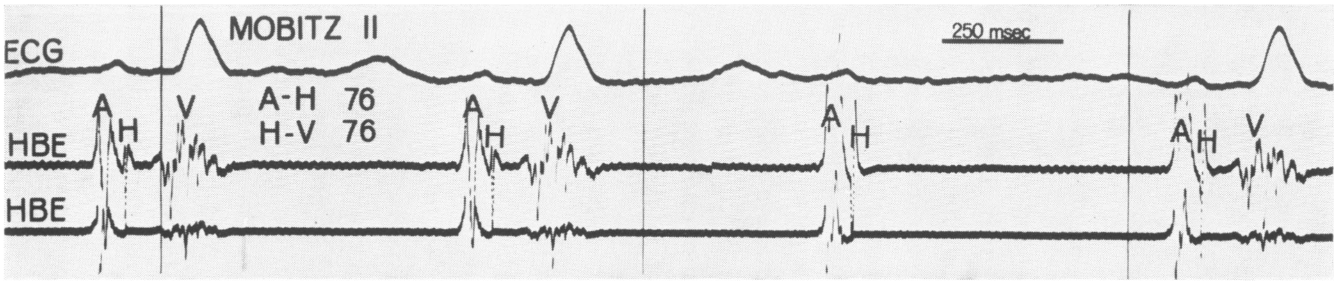

Fig. 12. Type II second-degree heart block. Patient with LBBB, constant P-R and P-P intervals. The A-H and H-V intervals of the first two beats are constant. The third atrial beat is unexpectedly blocked below the bundle of His. Reproduced by permission from: Damato, A. N. and Lau, S. H. *Progr. Cardiov. Dis. 13*:123, 1970.

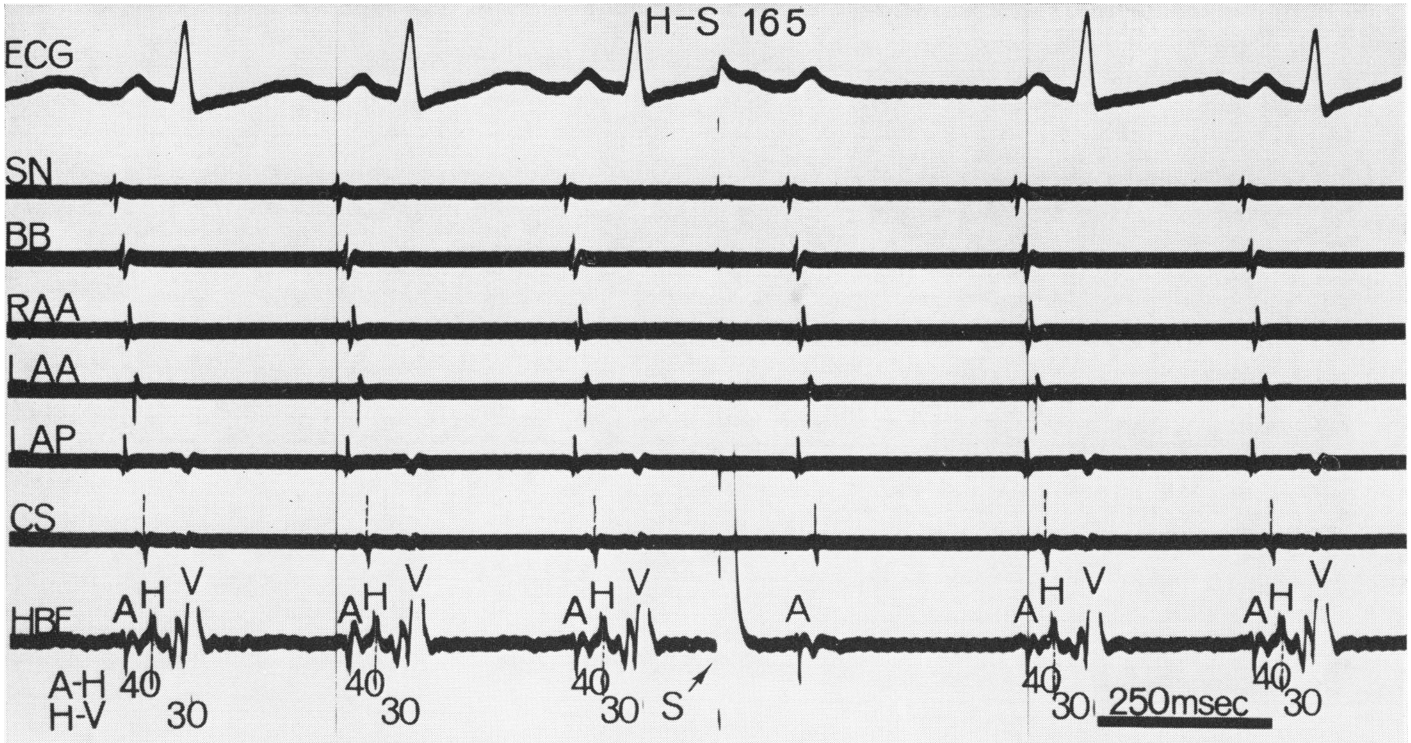

Fig. 13. Type 11 A-V block produced by concealed bundle of His extrasystoles. The first three atrial beats are conducted with constant A-H and H-V intervals of 40 and 30 msec. respectively. The bundle of His is prematurely stimulated at an H-S coupling interval of 165 msec. Retrograde concealed conduction of the premature His impulse produces block of the fourth atrial impulse; the sequence of atrial electrogram recordings is the same as shown in Fig. 9. Reproduced by permission from: Damato, A. N. et al. *Circ. Res.* *38*:316, 1971.

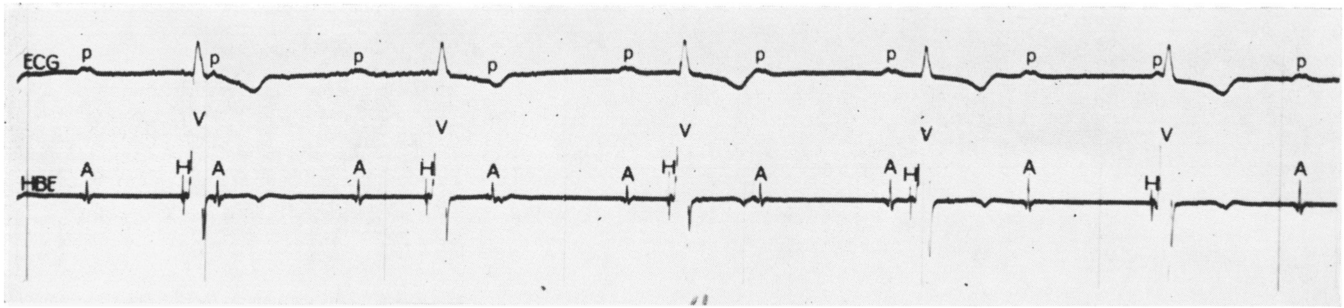

Fig. 14. Complete heart block with normal QRS complexes. The P-P and R-R intervals are constant and dissociated. Each of the nonconducted atrial impulses is blocked proximal to the bundle of His. The normal QRS complexes are each preceded by single His deflections with normal H-V intervals.

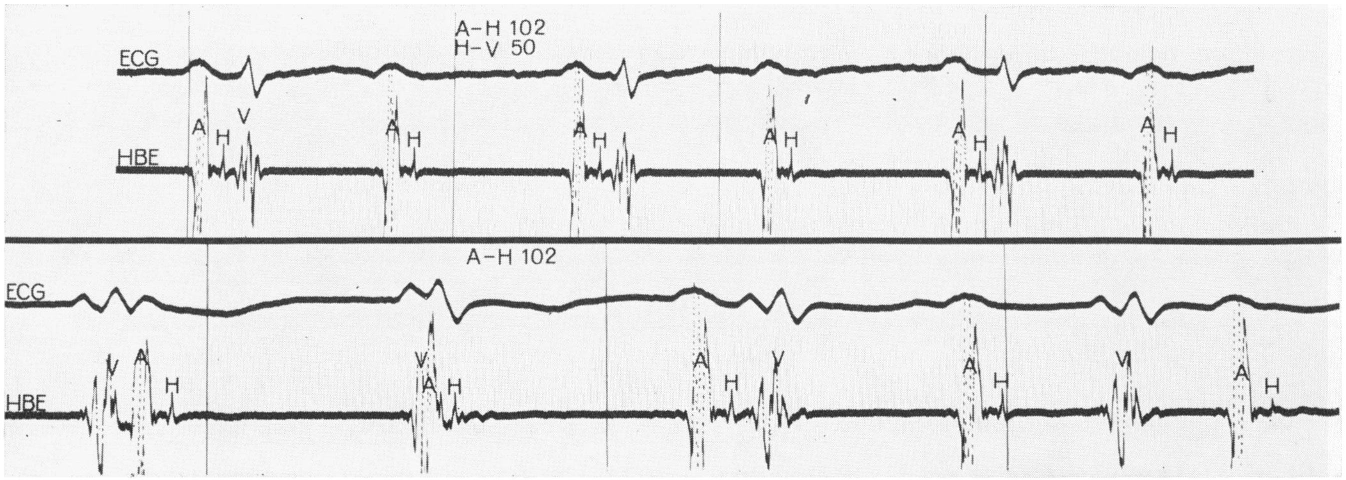

Fig. 15. Type 11 second degree heart block progressing to complete heart block with abnormal QRS complexes. ECG = lead II. This patient had RBBB with LAD. The top panel shows Type II second degree heart block. The bottom panel shows complete heart block with altered QRS complexes which are not preceded by His deflections, indicating that the pacemaker for the ventricles was subjunctional. The nonconducted atrial impulses are followed by His deflections. The vertical time lines represent 1000 msec. Reproduced by permission from: Gallagher, J. et. al.: *Couer Med. Interne.* In prees.

to indicate that reentry was present from the fourth atrial impulse on, and are not meant to indicate the actual time or site at which such reentry occurred. Premature atrial stimulation during sinus rhythm regularly produced atrial echoes or sustained SVT. Initiation of reentrant phenomena (echoes, SVT) was a function of A-V nodal delay rather than the coupling interval used, since reentry could be readily induced with straight atrial pacing using longer coupling intervals than was possible using single premature beats. Whenever A-V nodal delay of 160 msec. or more occurred (whether this was due to straight pacing or single prematurely stimulated atrial impulses), reentry occurred. Appropriately timed premature atrial stimuli could also terminate SVT in this patient.

Type II Second Degree A-V Block

Type II second degree A-V block is less commonly observed than Type I and is usually characterized by constant P-R intervals with unexpected dropped ventricular beats. The P-P interval is therefore fairly constant. This type of block is usually associated with a pattern of bundle-branch block and frequently progresses to high degree (2:1) and complete heart block. Our findings as well as those of other workers confirm that block below the bundle of His occurs during Type II block. Patients in whom Type II block occurs generally require permanent ventricular pacing. Figure 12 is an example of Type II A-V block in a patient who presented with syncopal episodes. The electrocardiogram revealed a LBBB pattern with constant P-R intervals and unexpected single and multiple nonconducted atrial impulses. His bundle recordings revealed that failure of conduction occurred within the His-Purkinje system.

Type II Block Produced by Concealed Bundle of His Extrasystoles

An example of bundle of His extrasystoles producing the electrocardiographic pattern of Type II second degree A-V block is presented in Figure 13. The bundle of His was prematurely stimulated (S) after the third sinus beat. The His extrasystole failed to propagate antegradely (no ventricular response) but was retrogradely conducted and concealed in the A-V node which caused block of the fourth atrial impulse.

2:1 A-V Block

2:1 A-V block presents a special problem in that it does not readily fit into either type of second degree A-V block according to presently used electrocardiographic criteria. Close observation of 2:1 A-V block will usually reveal a transition from or to lesser or greater degrees of A-V block, thus allowing classification based on behavior of the P-R intervals during these states. During fixed 2:1 block electrode catheter recordings can be utilized to identify the site of block. Demonstration of block below the bundle of His permits the diagnosis of Type II block to be made. Absence of a His deflection after the nonconducted atrial impulses strongly suggests Type I block. In our experience high degree A-V block in the presence of a normal QRS complex is almost invariably due to block within the A-V node, representing an extension of Type 1. 2:1 A-V block in the presence of a bundle-branch block pattern may represent either Type I (A-V nodal block) or Type II (His-Purkinje block).

Complete Heart Block

Complete heart block may be associated with normal or abnormal QRS complexes. In the former, the nonconducted atrial impulses are generally blocked proximal to the bundle of His and each normal QRS complex is preceded by a single His deflection. An example of this form of complete A-V block is illustrated in Figure 14. Narula and his associates have described patients in whom each of the nonconducted atrial impulses were consistently followed by a His deflection and, in addition, each of the dissociated normal QRS complexes were preceded by a single His deflection.[27] In these patients the level of block and the pacemaker for the ventricles were both at the common bundle.

Figure 15 is an example in which Type II A-V block progressed to complete heart block. This patient had RBBB with LAD and 2:1 A-V block. The top panel reveals that each of the nonconducted atrial impulses is blocked within the His-Purkinje system. During complete heart block (bottom panel) all of the nonconducted atrial impulses are followed by His deflections. Since the wide QRS complexes are not preceded by His deflections, the pacemaker for the ventricles was subjunctional.

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